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Hydrogeology and Water Supply Wells
Lava Beds National Monument

Natural Resource Report NPS/NRPC/WRD/NRTR—2007/373

ON THE COVER
Cinder butte and the Callahan lava flow near the park's south boundary
Photograph by: NPS

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Lava Beds National Monument

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Summary

Lava Beds National Monument is on the north slope of the Medicine Lake Volcano. It is underlain by a series of very permeable lava flows from eruptions of the volcano and older eruptive centers. Infiltration of rainfall and snowmelt on the slopes of the volcano recharge the underlying aquifer system. The lava flows are a source of abundant groundwater, as evidenced by the large number of high-volume irrigation wells that have been constructed adjacent to the park.

Groundwater supplies can be developed anywhere in the monument if wells are drilled deeper than the water table. The water table is at an elevation of approximately 4010 feet above mean sea level (msl). Groundwater quality is better in the southern part of the monument. In the northern part of the monument, groundwater quality is degraded by infiltration of surface water from the Tule Lake Sump into the lava flows.

Geothermal energy projects have been proposed for the Medicine Lake area, several miles southwest of the monument. It appears that the public land leases for both of the proposed projects will be rejected, although that is not certain. The distance between the monument and the proposed developments and the intervening geologic conditions make it unlikely that there would have been any direct impact to the monument's water resources. Park staff should remain vigilant to the potential for renewed proposals for geothermal energy development, as each project should be evaluated individually. The biggest impacts to the monument from geothermal development would probably be from ancillary development: roads, power lines, traffic, noise, night sky lighting, etc.

Beginning in 2001, groundwater pumping to supplement surface water sources increased markedly in the Tule Lake Groundwater Subbasin. Water levels in wells in the monument declined 1½-2 feet per year from late 2001 to spring 2005. It can not yet be determined how much of this decline was caused by groundwater pumping and how much should be attributed to the effects of a severe drought in 2001-02, with drier than normal conditions persisting into the early part of 2005. Water levels stabilized or rose slightly since 2005 corresponding to the onset of wetter than normal conditions. Continued monitoring of groundwater levels is recommended

to help identify the cause of water level fluctuations and to provide an early warning of changing hydrologic conditions.

Introduction

Lava Beds National Monument is located in Northern California, about 35 miles south of Klamath Falls, Oregon. The monument was established in 1924 to preserve the historic battlegrounds of the Modoc Indian War of 1872-73 and the many unusual volcanic features resulting from the eruptions of the Medicine Lake Volcano to the south. It is the purpose of this report to summarize hydrogeologic conditions of the monument, provide an inventory and history of water well construction in the monument, and provide an assessment of potential threats to the groundwater flow system underlying the monument.

Lava Beds National Monument is underlain by a series of basaltic lava flows that erupted from the Medicine Lake Volcano and flowed northward and deeper lavas from older eruptive centers. The lava flows are very permeable, allowing the water table under the monument to be nearly flat at an elevation of about 4010 feet above sea level. Groundwater is recharged by infiltration of rainfall and snowmelt on the Medicine Lake highlands south of the monument and inflow of groundwater from that part of the Upper Klamath Basin north of the monument. The monument is in the Tule Lake Groundwater Subbasin, as defined by the California Department of Water Resources (2004).

Much of the Tule Lake basin north of the monument was covered by a shallow lake until it was drained, starting in 1912, to create agricultural land. Farm land was historically irrigated with surface water from the Klamath Project. Groundwater pumping in the area has increased markedly since 2001 in response to changes in surface-water management in the basin and a series of consecutive drier-than-average years. The increased groundwater pumping is largely a result of U.S. Bureau of Reclamation programs to substitute groundwater for surface water for irrigation in the basin and to use groundwater to augment surface water supplies to meet the needs of endangered fish species.

The Oregon District of the U.S. Geological Survey and the California Department of Water Resources have conducted studies to evaluate the availability of groundwater for irrigation supplies and to assess the effect of increased groundwater pumping.

Geothermal development has been proposed in the vicinity of the Medicine Lake Volcano. Although the source of geothermal water would be much deeper and geologically separated from the shallow groundwater systems, surface activities associated with development of the geothermal resource could potentially affect water quality in the shallow groundwater system. Although the current proposals, Telephone Flat and Fourmile Hill, planned minimal use of shallow groundwater, future proposals for geothermal developments in the vicinity might plan to use large amounts of shallow groundwater for cooling or other purposes. Thus, there is a need to remain vigilant with respect to future proposals.

Previous Investigations

Berkstresser (1965) reported on the results of drilling and testing of a well at Captain Jacks Stronghold in the northern part of the monument. He also tested the production of the well at Gillems Camp. He concluded that the well at Captain Jacks Stronghold would sustain a pumping rate of about 20 gpm. The well at Gillems Camp was pumped at 18 gpm for 40 minutes resulting in a stable drawdown of 1.2 feet. This test was too short to determine a long-term sustained yield for the well.

Hotchkiss (1968) conducted a geologic and hydrologic reconnaissance of the monument for the purposes of evaluating the water-bearing characteristics of the geologic units and determining the source, occurrence, movement, and chemical quality of groundwater underlying the monument. The intent of the report was to provide the park with a document to guide future development of groundwater for visitor and administrative facilities in the monument. The investigation included drilling test wells at the Petroglyph Section, Fern Cave, Whitney Butte, and the Southeast Entrance. Hotchkiss provided a hydrogeologic cross section (Figure 1) that illustrates the relationship of the lake sediments underlying the basin to the north of the monument and the volcanic rocks that underly most of the monument. Hotchkiss concluded that a well drilled into the volcanic rocks underlying the monument should provide ample amounts of water for visitor use. Better quality groundwater would be obtained from wells located further south in the monument, away from the influence of surface water inflow from Tule Lake Sump.

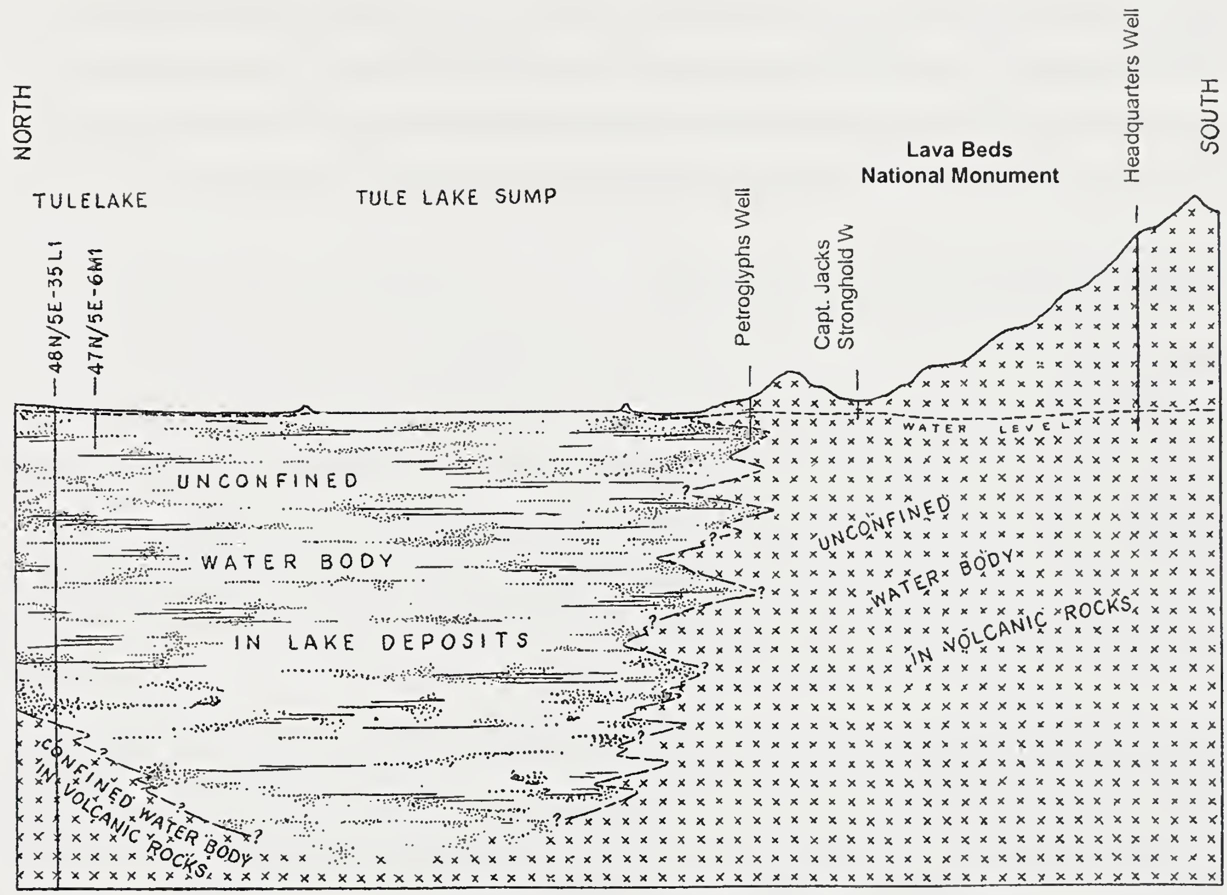

Figure 1. Hydrogeologic cross section through Lava Beds National Monument.
(from Hotchkiss, 1968)

Donnelly-Nolan and Champion (1987) produced a geologic map and description of Lava Beds National Monument. Donnelly-Nolan, along with several different coauthors, produced numerous geologic maps and reports for the Medicine Lake Volcano and surrounding area. References for these reports are provided in the text accompanying the geologic map (Donnelly-Nolan and Champion, 1987).

The California Department of Water Resources (2003) report on California's groundwater includes a general summary of the hydrogeology and groundwater resources of the Tule Lake Subbasin.

Gannett et al. (2007) completed a comprehensive report of the groundwater hydrology of the Upper Klamath Basin in California and Oregon. Water-level data show that groundwater from

the northern part of the upper Klamath Basin flows into the Tule Lake Subbasin and may continue flowing in a southerly direction out of the Tule Lake Subbasin. It is suggested that north-northwesterly trending fault zones may create permeable pathways for groundwater to flow toward the south, out of the Tule Lake Subbasin toward the Pit River Basin.

HYDROGEOLOGIC SETTING

Hydrogeology

The principal water-bearing formations underlying Lava Beds National Monument are volcanic rocks, primarily lava flows from the Medicine Lake Volcano to the south of the monument and underlying lavas of the Modoc Plateau. In the northern part of the monument, there is some interfingering of lava flows and lake sediments underlying Tule Lake. Principal geologic formations underlying the monument include:

Pleistocene Upper Basalt. This unit is an unweathered basalt lava flow that is very permeable due to extensive fracturing. This rock unit is exposed at the surface over most of the area of the monument. The porous nature of the lava facilitates high infiltration and recharge rates for the groundwater flow system. The fractured basalt rocks yield large quantities of water to wells, up to several thousand gallons per minute.

Pleistocene Intermediate Basalt. This unit is a series of thin-bedded basalt lava flows. These lava flows interfinger with lakebed sediments at the northern part of the monument. These rocks are generally very permeable due to well-developed columnar jointing and an abundance of bedding planes. Wells constructed in this unit will often yield large quantities of water, up to several thousand gallons per minute.

Pliocene to Holocene Lake Deposits. The lake deposits consist of sand, silt, clay, volcanic ash, lenses of diatomite, and semi-consolidated shale. Poorly sorted deposits have low permeability and act as confining layers to the interfingering basalt lava flows. Wells constructed in the sediments generally yield only small amounts of water, up to a few tens of gallons per minute.

Pliocene to Miocene Lower Basalt. The older basalt comprises a very permeable aquifer system that is commonly confined where it underlies the lakebed sediments north of the monument. These older basalt flows might better be described as a series of interconnected aquifers. Some wells completed in the lower basalt yield more than 10,000 gpm.

Tule Lake Groundwater Subbasin

Lava Beds National Monument is located in the Tule Lake Groundwater Subbasin, which is a portion of the Upper Klamath River Groundwater Basin in northern California and southern Oregon (California Department of Water Resources, 2004). The Tule Lake Subbasin is bounded on the west by the Gillems Bluff Fault, which extends beneath and is a major structural feature of the Medicine Lake Highlands. The fault forms a steep escarpment in the northern part of the monument but is buried by recent lava flows in the southern part of the monument. The subbasin is bounded on the east by the Big Crack Fault, a north-south trending fault which forms the western edge of the block faulted mountains between Tule Lake and Clear Lake Reservoir. The subbasin is bounded on the south by the remnant caldera rim on the north flank of the Medicine Lake Volcano. To the north, the subbasin extends into Oregon where it is bounded by the northwest trending faults on the south side of the mountain block dividing the Poe Valley from the Tule Lake Valley. Figure 2 shows the approximate extent of the arbitrary administrative boundary of the Tule Lake Groundwater Subbasin, as defined by California Department of Water Resources (2004). This administrative boundary should not be misconstrued as a physical boundary for the groundwater flow system. Groundwater flows into the subbasin from the north and out of the subbasin to the south-southeast.

Historically, groundwater use in the Tule Lake Subbasin had been relatively minor. Abundant surface water was available for irrigated agriculture from the U.S. Bureau of Reclamation's Klamath Project. In 2001, water requirements for two species of sucker fish in the upper part of the Klamath Basin and coho salmon in the lower Klamath Basin caused the USBR to reduce surface water delivery to farmers to 26% of normal. The reduced deliveries were exacerbated by drought conditions in the area. In subsequent years, surface water deliveries have been near normal.

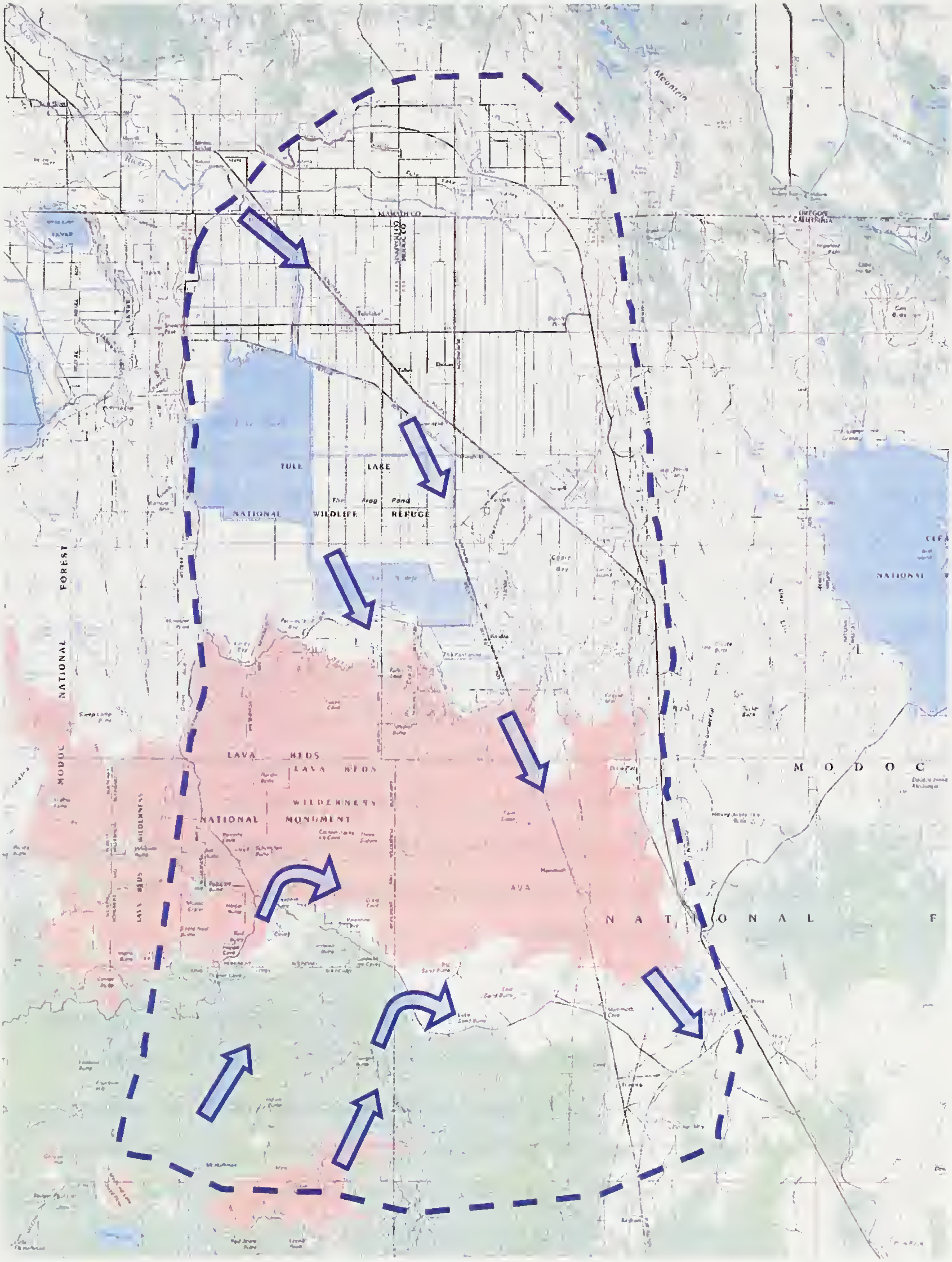

Figure 2. Approximate extent of the Tule Lake Groundwater Subbasin, California Department Water Resources administrative boundary. Arrows show general direction of groundwater flow.

A "water bank" project was initiated in 2003 as mandated by the 2002 NOAA Fisheries Biological Opinion (National Marine Fisheries Service, 2002) for the operation of the Klamath Project and its effects on Klamath River coho salmon. The water bank substitutes groundwater for irrigation supplies, allowing more surface water to remain in the streams for fish habitat. Much of the groundwater pumping for the water bank occurs from the Tule Lake Groundwater Subbasin. Since 2001, at least 35-40 large-volume irrigation wells have been constructed in the California part of the Tule Lake Subbasin to provide an alternative source of irrigation water. Pumping from these wells has caused a lowering of the water table in the immediate area of the wells. Groundwater levels in an area northeast of the park declined 5-10 feet between spring 2001 and spring 2004 (Gannett et al., 2007).

In general, groundwater enters the Tule Lake Subbasin as underflow from the northern parts of the Upper Klamath Basin, from the west, and from the Modoc Plateau east of the Tule Lake Ssubbasin. Additional inflow to the groundwater system is provided by infiltration of rainfall and snowmelt on the northern slopes of the Medicine Lake Volcano. Groundwater leaves the subbasin as underflow toward the south-southeast, east of the Medicine Lake Volcano. There may also be shallow groundwater discharge to the Tule Lake Sump, from which water is pumped by a Bureau of Reclamation pumping plant to the Lower Klamath Lake Basin.

Recharge Areas

Groundwater in the basalt lava flows is rapidly replenished by infiltration of rainfall and snowmelt on the north-facing slope of the Medicine Lake Volcano. The area contributing recharge to the groundwater flow system underlying the monument likely extends about 5-6 miles south of the monument to the Mt. Hoffman area. Mt. Hoffman is the highest point on the rim of the collapsed caldera of the Medicine Lake Volcano. Low permeability rocks (formed by mineral deposition and alteration) associated with the rim of the caldera probably form the southern boundary of the Tule Lake Groundwater Subbasin.

Lava Beds National Monument is located on the north flank of the Medicine Lake Volcano. The recharge area above Lava Beds on this north-facing slope is approximately 35 square miles. This high summit area is mostly forested. The area is underlain by very porous lava flows. Both the

rain and snowmelt in the area readily infiltrate into the porous lava and volcanic rock, and are the primary source of recharge for the groundwater flow system underlying the monument. There is no surface water flow on the north flank of the volcano; all of the rainfall and snowmelt not transpired by the plants or evaporated from the soil and vegetative surfaces infiltrates to the groundwater system.

Groundwater Quality

Water quality from wells completed in the unconfined volcanic rocks is very good. It has a sodium-bicarbonate character and a total dissolved solids concentration ranging from about 150-270 mg/l. Water quality from wells that are closer to the lakebed sediments (e.g., in the northern part of the monument) has a sodium/calcium/magnesium-bicarbonate/sulfate signature that has a much higher concentration of total dissolved solids (600-800 mg/l), which generally increases in proportion to the cumulative thickness of the interfingering lakebed sediments that are penetrated by a well.

Hotchkiss (1968) stated that the chemistry of groundwater underlying the monument would be better suited for human consumption approximately south of an east-west line through Juniper Butte. North of this line, groundwater closer to Tule Lake Sump generally is of poorer quality due to inflow of surface water from the sump to the basalt underlying the monument. Groundwater quality data from wells in the monument are tabulated in Table 1.

Table 1. Water quality from wells at Lava Beds National Monument.

Well	Date	TDS	Sp. Cond.	pH	Hardness	Ca	Mg	Na	K	HCO_3	CO_3	SO_4	Cl	F	NO_3	Fe
Captain Jacks Stronghold	11/4/64	800	1190	8.4	376	72	48	101	14	324	8	246	34	0.2	24	7.6
Gillems Camp	7/26/62	---	868	7.2	344	64	45	62	12	424	0	97	4.4	0.2	12	---
Gillems Camp	10/30/64	638	976	8.2	384	72	50	60	9.1	450	0	113	26	0.2	14	1.5
Gillems Camp	6/7/66	609	915	7.8	376	74	47	61	13	438	0	109	24	0.4	15	0.12
Petroglyph	5/8/66	573	921	8.2	322	46	50	91	11	544	0	65	18	0.4	0.5	0.02
Headquarters	8/9/65	156		8.2	33.5	5.9	4.5	25.3	2.4	71.8	0	0.3	13.2	0.4	0.3	0.23
Headquarters	3/18/85	138	180	7.8	30	6	4	26	3	92	ND	1	15	0.3	1	<0.1

Values for specific conductivity (Sp. Cond.) are umhos/cm. pH is in standard pH units.
All other values are mg/l.

Well Inventory

The water supply well for the monument is located in the headquarters area and supplies water for the visitor center, campground, park offices, and employee housing. The headquarters area is the only area of the park with a public water supply system. Water use from other wells at the monument was discontinued decades ago. Those wells now are used only for monitoring groundwater levels.

Figure 3 shows the location of wells that have been drilled at Lava Beds National Monument. Construction information for wells and test holes at the monument are included in Table 2. Hydrographs showing measured water levels in wells at the monument are included as Figures 4-10. An explanation of the well numbering system is included in the appendix of this report.

Table 2. Construction data for water wells and test holes at Lava Beds National Monument

Location	Name	Depth	Year Constructed	Lat/Long DMS	Status
T45N R4E 28H1	Headquarters	758	1939	414300/1213024	Water Supply
T46N R4E 18J1	Gillems Camp	226	1935	414934/1213321	Monitor Well
T46N R4E 15M1	Captain Jacks Stronghold	48	1964	414931/1213034	Monitor Well
T46N R5E 3P1	Petroglyph Section	173	1966	415104/1212329	Monitor Well
T46N R5E 19M1	Fern Cave	120	1966	414844/1212719	Monitor Well
T45N R3E 14J1	Whitney Butte	90	1966	414430/1213515	Abandoned
T45N R4E 36K1	Southeast Entrance	270	1966	414145/1212725	Abandoned

Figure 3 also shows the location of one of the many wells where the California Department of Water Resources makes regular water level measurements. Well 46N-5E-16N is outside the monument boundary, in an area with several large-volume irrigation wells.

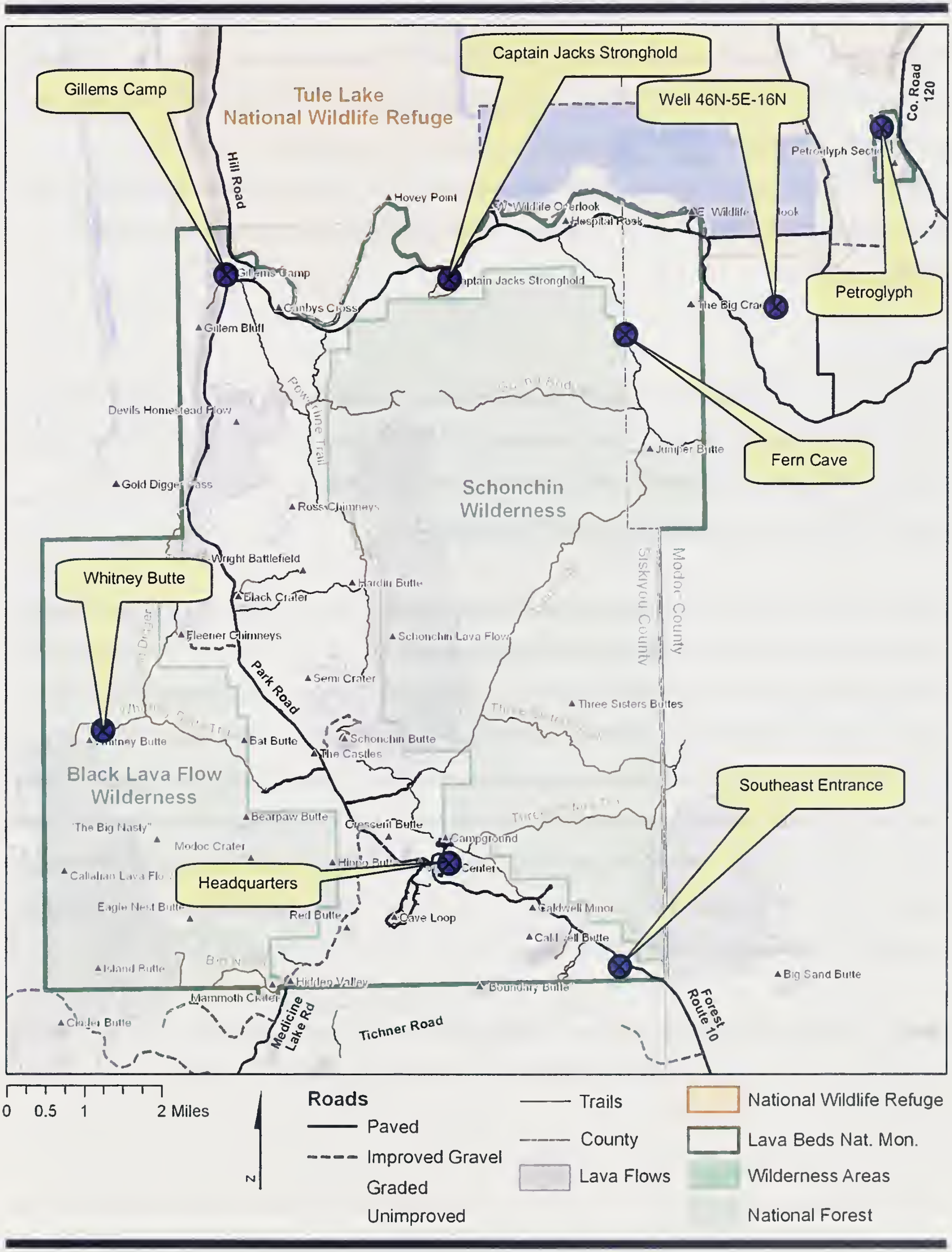

Figure 3. Location of wells and test holes at Lava Beds National Monument.

In May 1966, test drilling was conducted at four locations in the monument to explore for groundwater. The test hole in the Petroglyph Section was completed as a water well. The Fern Cave test hole was completed as a water level monitoring well. At Whitney Butte, the test hole could only be drilled to 90 feet and was dry. The hole was abandoned. At the Southeast Entrance, the first two test holes were abandoned due to drilling problems and the third test hole was abandoned at 270 feet because the bit had become stuck and was sheared off while attempting to free it.

Headquarters

The well at the Headquarters area of the monument was constructed in June and July 1939. The well is located in the SE¼ of the NE¼, Section 28, T45N, R4E (Figure 3). The well is 758 feet deep and was constructed entirely in basalt and lava flows. Depth to water in the well is measured with a pressure gauge connected to an airline.

Larger capacity pumps have been installed in the well over the years as the demand for water at the monument increased. The most recent information in NPS Water Resources Division files is regarding replacement of the pump in 1993. At that time the 45 gpm, 20 hp pump was replaced with an 80 gpm, 30 hp pump. The static water level was measured at 663.8 feet. After pumping the well 23 hours the depth to water, as determined with the pressure gauge and airline, was 664 feet below ground surface. This would indicate that the well is capable of producing much more water. When the pump was replaced in 1993, it was observed that the intake screen on the old pump was partially plugged with rust flakes. This is likely corroded steel from the inside of the well casing. This is fairly common for a well that is more than 50 years old.

In May 2005 park staff attempted cyclic replacement of the pump in the Headquarters Well. The old pump could not be removed, leading to the conclusion that the casing had partially collapsed onto the pump. Historically, the pump has burned out every 9-10 years. The pump currently in the well was installed in 1993, 14 years ago. The park attempted to construct a new well in 2005, but a variety of construction problems have thus far prevented successful completion of a new well. The new well will be constructed into the same basalt and lava flow aquifer as the old well. Construction of the new well is expected to be completed in summer 2007.

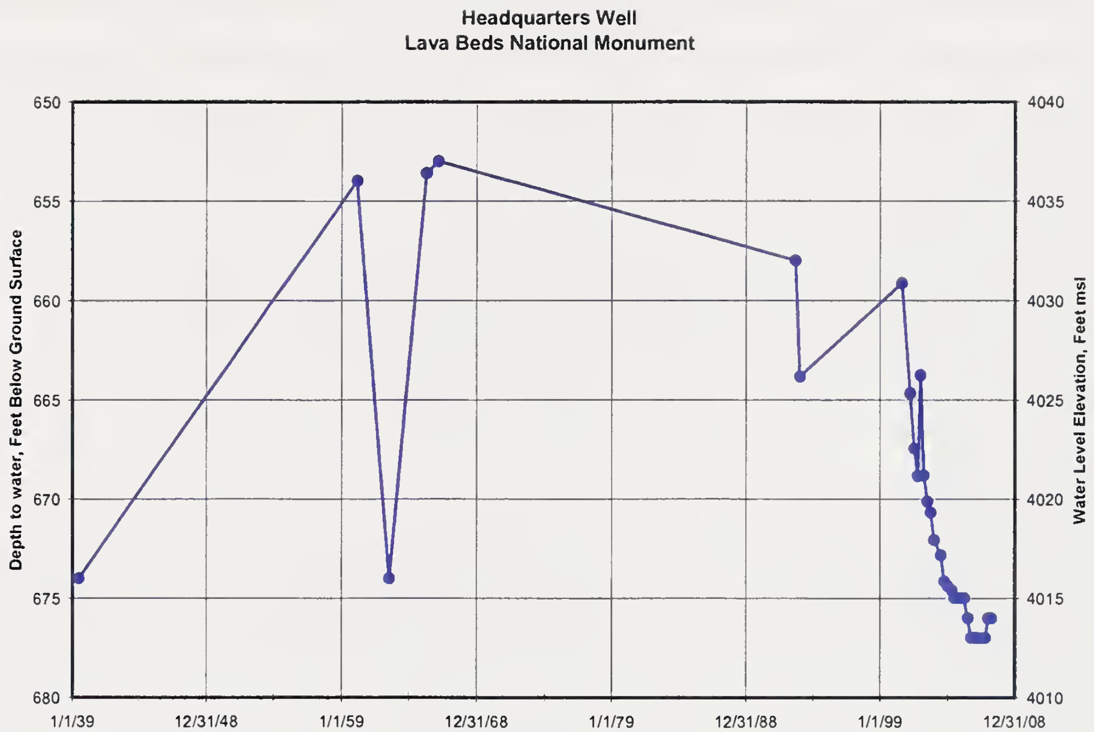

Figure 4. Water levels in the Headquarters Well.

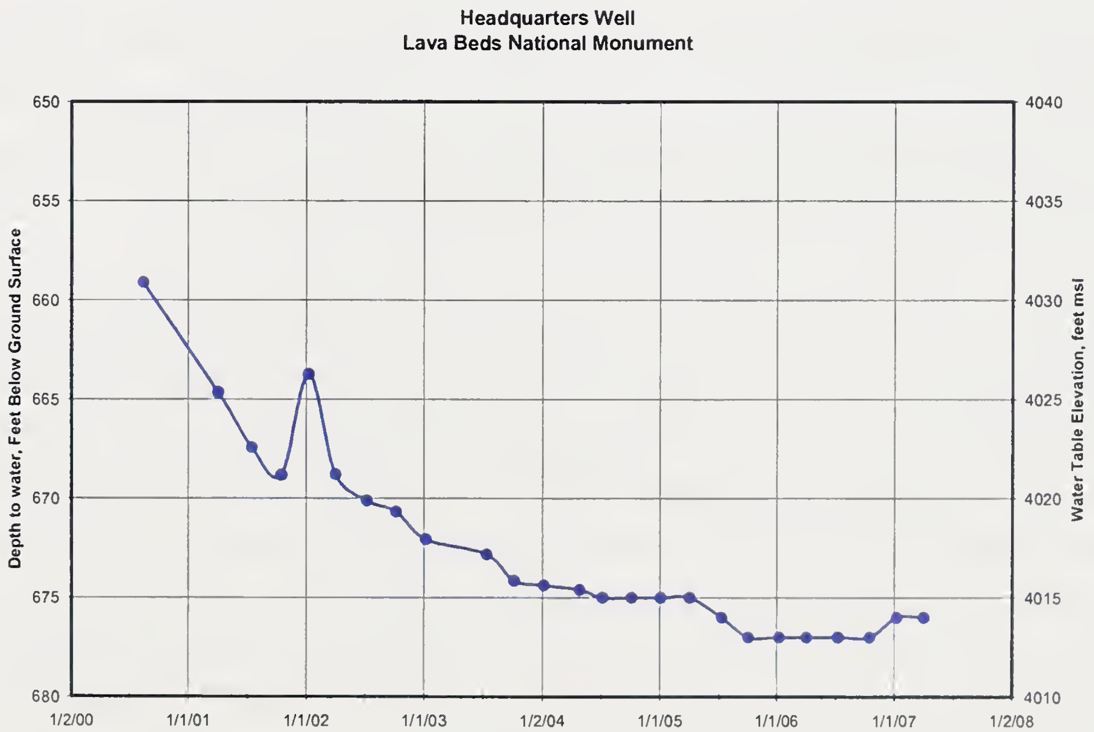

Figure 5. Recent water levels in the Headquarters Well.

The water level in this well was reportedly 674 feet below ground surface when the well was constructed in 1939. Most water level measurements until 2000 were between 654 and 664 feet below ground surface (Figure 4). The USGS began more regular monitoring of water levels at this well in 2000. Since then, water levels have declined from about 660 to 677 feet below ground surface (Figure 5). The largest water level decline was observed in 2000 and 2001, prior to the increase in groundwater pumping for irrigation in the region starting in 2002. The rate of decline has decreased from 2002 to present, indicating that perhaps the decline was more in response to low recharge rates during the drought rather than due to groundwater pumping.

Gillems Camp

The well at Gillems Camp near the northwest entrance to the monument is located in the NE¼ of the SE¼, Sec. 18, T46N, R4E (Figure 3). It was completed on May 10, 1935, and was drilled to 226 feet deep. The well was drilled through lake sediments to a depth of 175 feet, then through basalt from 175-195 feet, then back into lake sediments from 195-210 feet, and then back into basalt from 210-226 feet. The principal water-bearing formation, as noted by the well driller, is a sand layer from 203-210 feet below ground surface.

The well was test pumped and water quality samples were collected on October 30, 1964. The static water level was 56 feet below ground surface. The well was pumped for 40 minutes at 18 gpm. Drawdown stabilized at 1.2 feet after 5 minutes of pumping. The water is hard, but has less sulfate and iron than the water from the well at Captain Jacks Stronghold.

The depth to water in this well was reportedly 67 feet below ground surface when the well was constructed in 1935. Subsequent water level measurements were between 52-59 feet below ground surface (Figure 6) until the most recent measurements in 2005-07. The USGS sounded this well in August 2000 and found the bottom (or an obstruction) at 62½ feet below ground surface. Regular monitoring of water levels in this well by USGS personnel was initiated in August 2000. Water levels since then have trended downward with a seasonal increase in early summer, perhaps in response to recharge from snowmelt (Figure 7). It has not been determined whether the downward trend of water levels in the well has been caused by drought, increased groundwater pumping, or a combination of the two factors.

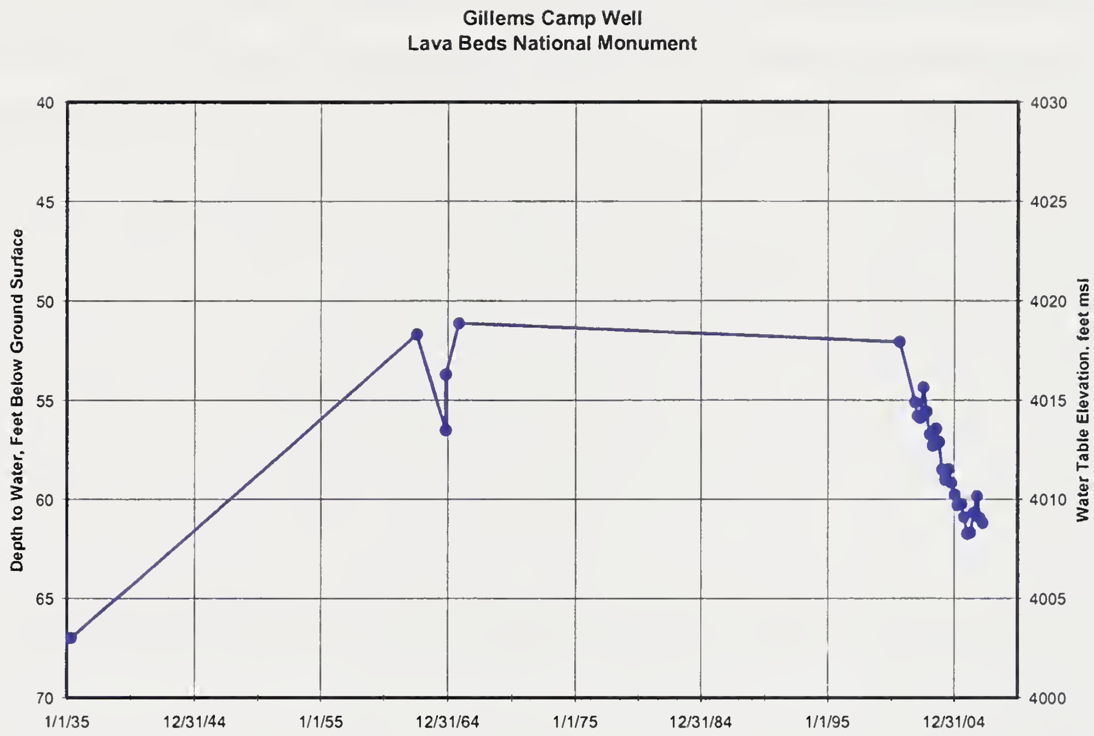

Figure 6. Water levels in the Gillems Camp Well.

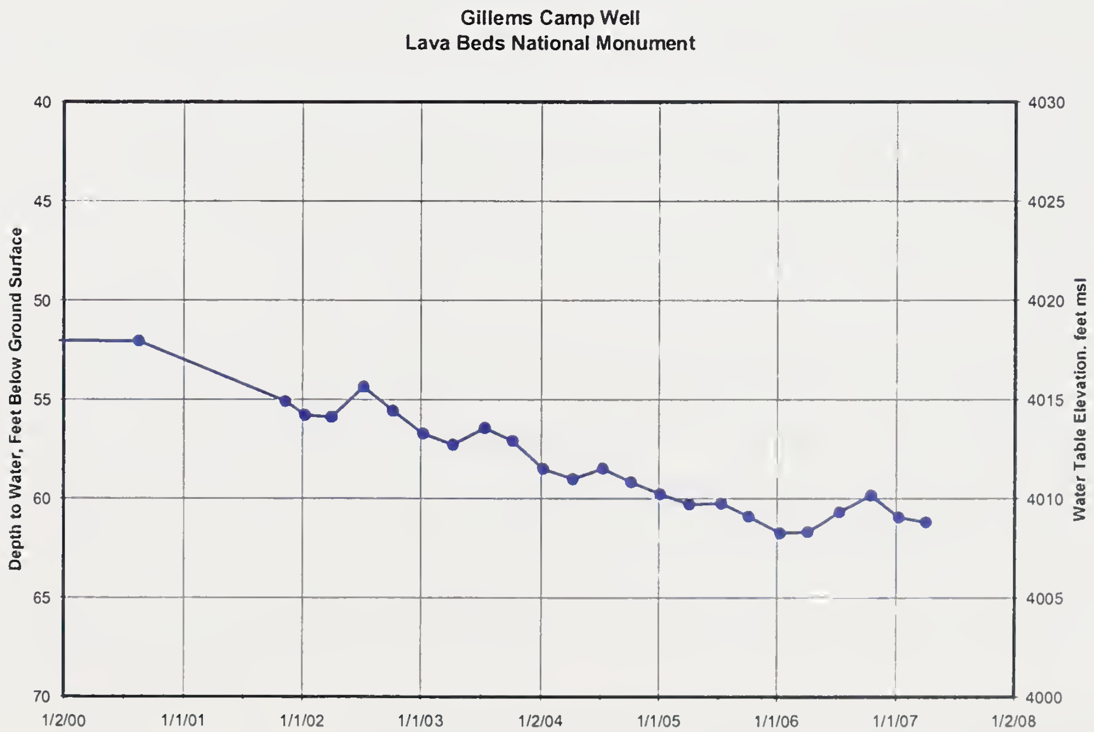

Figure 7. Recent water levels in the Gillems Camp Well.

Captain Jacks Stronghold

In October and November 1964, a well was drilled near Captain Jacks Stronghold. The well is located in the NW¼ of the SW¼, Sec. 15, T46N, R4E (Figure 3). It is about 140 feet south of the road into the monument and about 700 feet east of the exhibit area. The well was drilled into fractured basalt. The site was selected to avoid drilling into the sediments underlying the nearby Tule Lake because of the poor chemical quality of groundwater associated with those sediments. The well was drilled to 48 feet below land surface. The driller noted water entering the well from fractures in the basalt at 36-37 feet and 44-46 feet. Eighteen inch steel casing was installed from land surface to 33 feet, leaving the hole uncased from 33-48 feet. The water level in the well was 29 feet below ground surface after completion of the well on October 29, 1964.

A test pump was installed and the well was pumped for 24 hours at rates ranging from 22-38 gpm. The maximum sustained discharge rate was 25 gpm with a drawdown of 10½ feet (depth of water 39½ feet below ground surface).

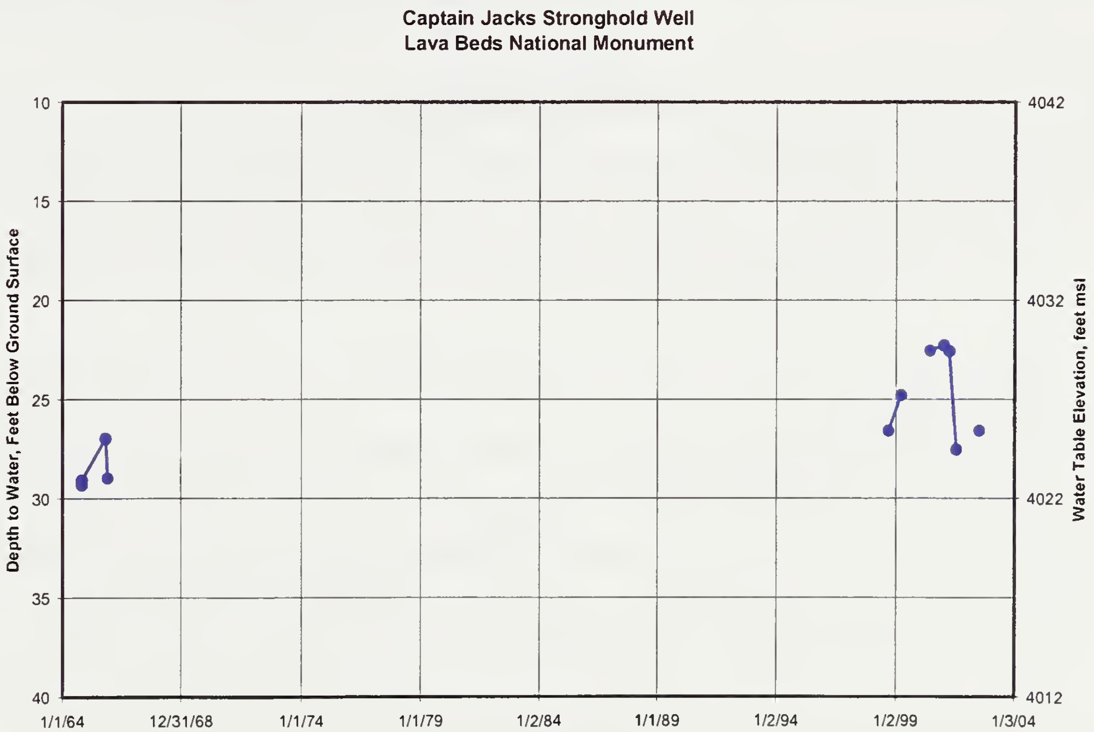

Figure 8. Water levels in the well at Captain Jacks Stronghold.

The well at Captain Jacks Stronghold yields adequate water, but has poor quality. Iron and total dissolved solids exceeds drinking water standards. The water is very hard and has a high concentration of sulfate.

Measured water levels in this well range from 22 to 29 feet below ground surface (Figure 8). No water level measurements have been made since 2002 because the water level has dropped lower than the bottom of the well. USGS personnel sounded the well in June 2000 and measured a total depth of 27.4 feet below ground surface, indicating that the lower part of the well has probably caved in.

Whitney Butte

This well was constructed as part of the test drilling program in the park in 1966. The test hole was located in the NE¼ of the SE¼, Sec. 14, T45N, R3E (Figure 3). The test hole was drilled to 90 feet. Caving conditions prevented deeper drilling. There is no indication that drilling reached the water table in this area.

The hole was abandoned. There is no record of whether the hole might have been backfilled or if it was simply abandoned as an open hole. It can be inferred from the description of work in the report (Kemp, 1966) that no casing was left in the test hole. Also, since there is no mention of hauling in material to backfill the holes and there is no native soil material on site to backfill the hole, it is likely that the hole was simply abandoned as an open, unplugged test hole.

Southeast Entrance

Three test holes were attempted at this location, NW¼ of the SE¼, Sec. 36, T45 N, R4E (Figure 3). One hole was drilled to 65 feet before circulation was lost and the hole was abandoned. The second hole was drilled to 24 feet and was abandoned because it was very crooked. The third hole was drilled to 270 feet before it was abandoned because the drill bit got stuck and the bit and 15 feet of pipe were sheared off in the hole.

The site was abandoned. There is no record of whether the hole might have been backfilled or if it was simply abandoned as an open hole. It can be inferred from the description of work in the

report (Kemp, 1966) that no casing was left in any of the three test holes at the site. Also, since there is no mention of hauling in material to backfill the holes and there is no native soil material on site to backfill the holes, it is likely that they were simply abandoned as open, unplugged test holes.

Petroglyph Section

The Petroglyph Section Well was constructed as part of the test drilling program in the park in 1966. The well is located in the SE¼ of the SW¼, Sec. 3, T46N, R5E (Figure 3). It was originally drilled to 173 feet deep, but caving and backfilling in the test hole resulted in a final well depth of 145 feet.

The well was completed by installing 4-inch casing to 89 feet below ground surface. The casing could not be forced deeper into the well due to an undetermined obstruction. The casing is perforated from about 47-89 feet. The well was left as an open borehole from 89-145 feet. A cement surface seal was installed from the surface to a depth of 10 feet. USGS personnel sounded this well and found the bottom, or an obstruction, at a depth of about 80 feet below ground surface.

The well was test pumped by air lifting. The finished well produced 49 gpm with about 3 feet of drawdown after 45 minutes of pumping. It was concluded that the well would produce ample amounts of water (Kemp, 1966). The well is currently being used to monitor groundwater levels. Water levels respond to seasonal pumping of a nearby irrigation well.

Water levels in this well were generally about 29 feet below ground surface in 2000, prior to construction of irrigation wells in the area. Water level measurements from 2002 to present generally range from 35 to 45 feet below ground surface with a downward trend (Figure 9).

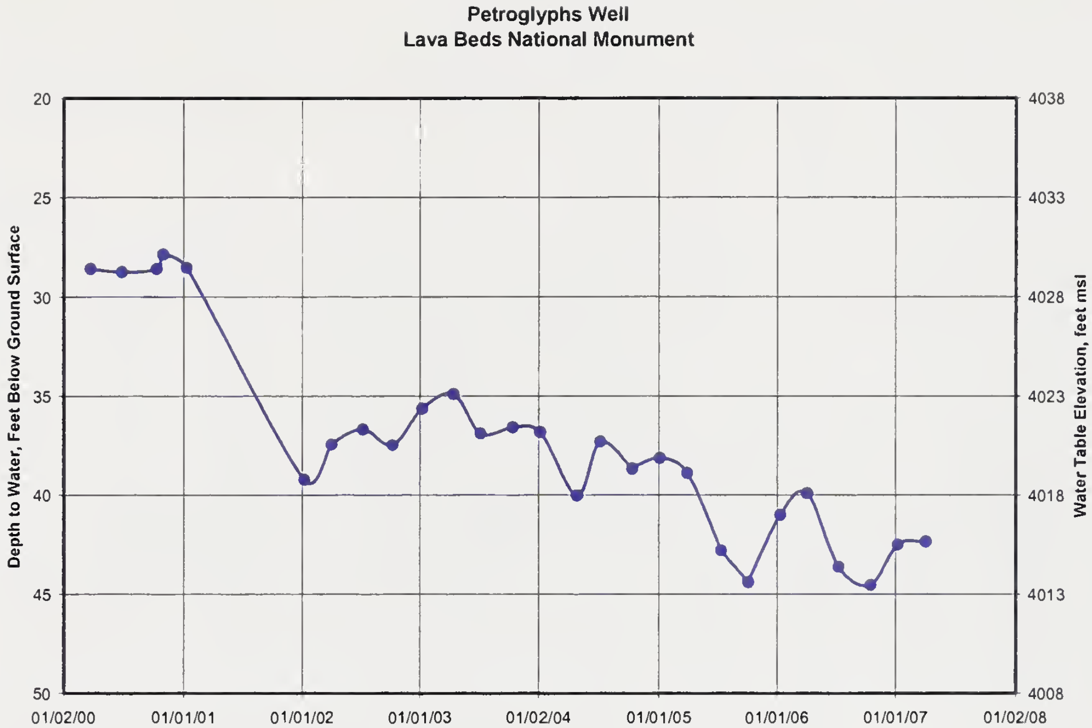

Figure 9. Water levels in the Petroglyph Section Well.

Fern Cave

The well at Fern Cave was constructed as part of the test drilling program in the park in 1966. The test hole is located in the NW¼ of the SW¼, Sec. 19, T46N, R5E (Figure 3). The test hole was drilled to 120 feet, but caving in the hole resulted in a well that is only 105 feet deep. The well was completed by installing 2½" PVC to 105 feet. A piece of galvanized steel pipe was attached to the top of the PVC to provide a more durable finished construction for the pipe exposed above ground surface. The perforated interval and number of perforations in the PVC pipe was not recorded in the report (Kemp, 1966). A ten foot cement surface seal was installed.

The well is currently being used as a water level monitoring well. The water level declined 6 feet from January 2001 to October 2003. The well has been dry since October 2003 (Figure 10). USGS personnel sounded the well in January 2003 and determined that the depth was 105 feet below ground surface.

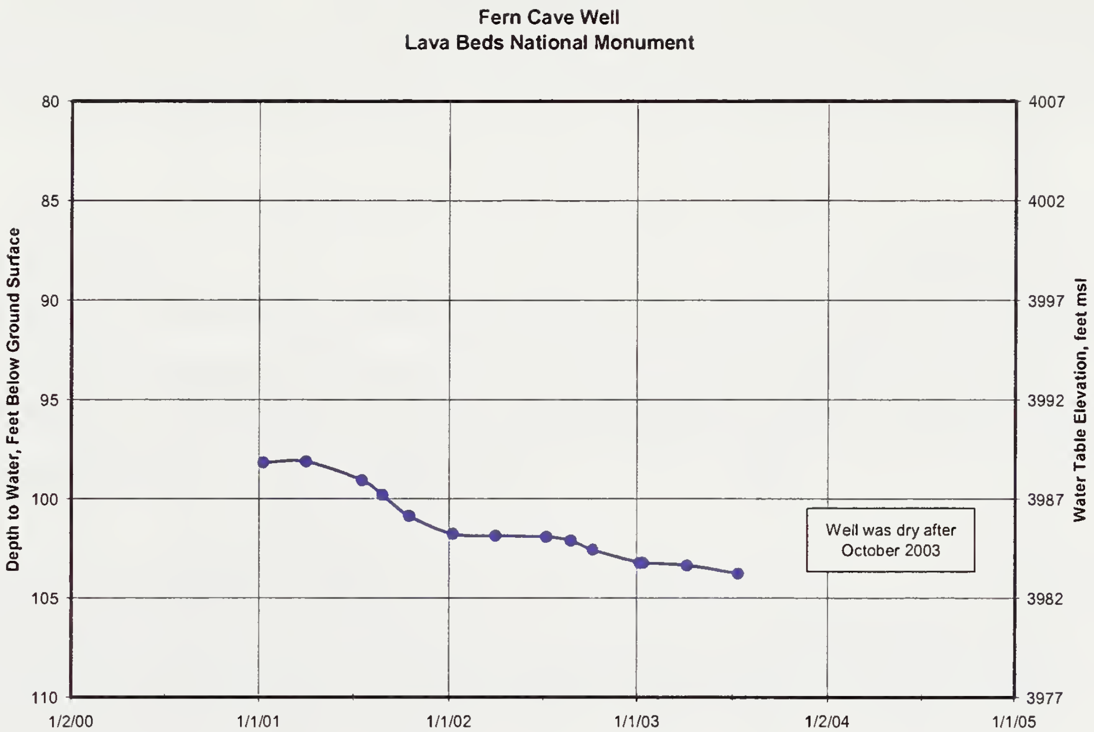

Figure 10. Water levels in the Fern Cave Well.

WATER USE AT THE MONUMENT

The well in the Headquarters Area is the only water supply well for the park. It is the sole source of potable water for the Headquarters Area water system. It provides potable water to the campground, visitor center, monument offices, and employee residences. The well supplies water for more than 110,000 visitors annually, producing about 5 to 6 million gallons annually as shown in Table 3. Water usage varies seasonally as shown in Figure 11.

Table 3. Annual water usage at Lava Beds National Monument

1999	5,445,950 gallons
2000	4,835,113 gallons
2001	6,109,900 gallons
2002	5,726,000 gallons
2003	5,843,330 gallons
2004	3,320,060 gallons
2005	2,979,680 gallons
2006	2,635,150 gallons

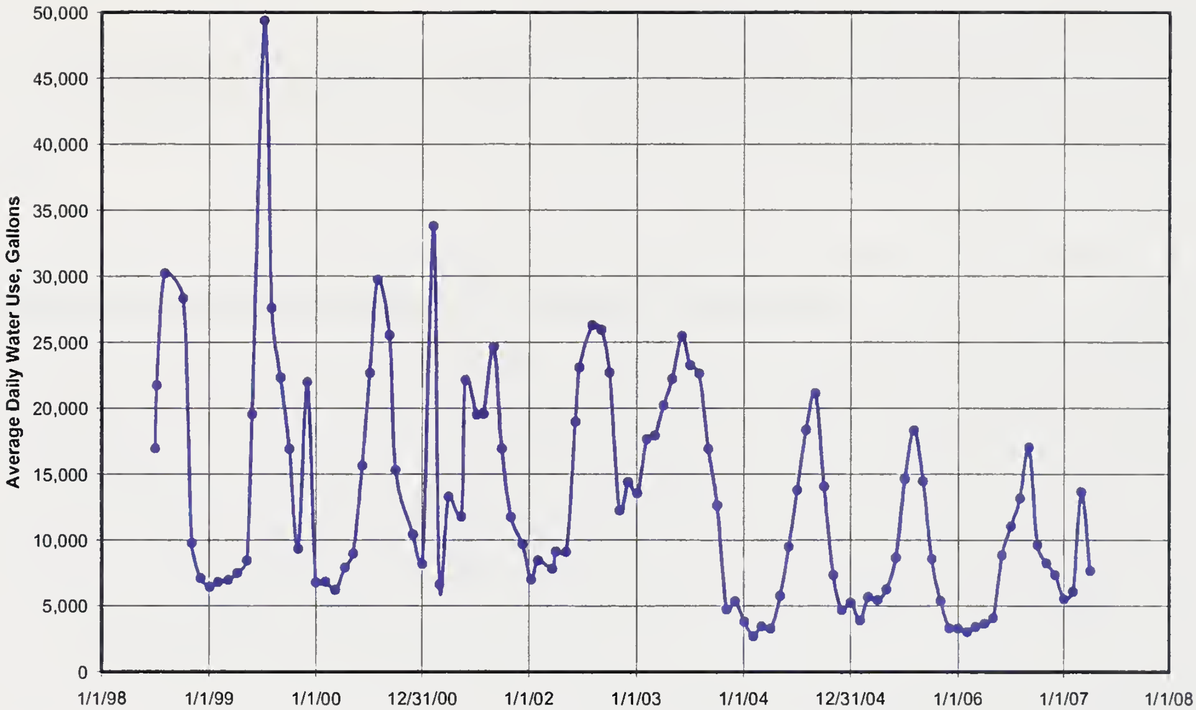

Figure 11. Average daily water use at Lava Beds National Monument.

Average daily water use at the monument from July 1998 to April 2007 is shown on Figure 11. Water use has been decreasing the past couple of years after repair of a couple of leaks in the water distribution system, conversion to low-volume plumbing fixtures, and implementation of water conservation measures. During the high visitor season in the summer, average daily water use is 15-20,000 gallons per day. During the winter, when there are very few park visitors, almost all of the water use is at the administrative and maintenance facilities and the NPS residential area in the monument. Winter usage averages 4-5,000 gallons per day. The spike in water usage in June 1999 is an unexplained anomaly. High use in winter and spring 2007 was due to a leak in the distribution system (that has been repaired) and the need for up to 11,000 gallons per day to drill the new well.

Visitor facilities at other areas of the park are not supplied with potable water. Restrooms in these areas, e.g. Gillems Camp and Captain Jacks Stronghold, have vault toilets.

Geothermal Energy Development

In the late 1990s, separate NEPA documents were prepared for two proposed geothermal projects south of Lava Beds National Monument.

The proposed location of the Fourmile Hill Geothermal Development Project was about 3 miles northwest of Medicine Lake, about 6 miles southwest of the monument boundary (location not shown on maps in this report). The Fourmile Hill Project was approved in May 2000. No development occurred pending the outcome of litigation related to the project. In November 2006, the U.S. Court of Appeals for the Ninth Circuit reversed a lower court ruling and rejected the 1998 and 2002 energy leases made by the federal government to Calpine Corp. The decision could be appealed to the U.S. Supreme Court, the project could be abandoned, or the Forest Service and Bureau of Land Management could start over with the leasing process with appropriate environmental and cultural reviews.

The proposed location of the Telephone Flat Geothermal Development Project was about 1½ miles east of Medicine Lake, 7-8 miles south of the monument boundary (location not shown on maps in this report). The proposal for the Telephone Flat Project was initially denied in May 2000. That decision was reversed in November 2002. No development occurred pending the outcome of litigation related to the project. Although the U.S. Court of Appeals 2006 decision applied only to the Fourmile Hill Project, there is a lawsuit pending on the Telephone Flat Project based on grounds similar to the lawsuit which resulted in denial of the leases for the Fourmile Hill Project.

While it would appear that there will be no geothermal energy development in the area in the near future, park staff should remain vigilant with respect to the final disposition of the Telephone Flat and Fourmile Hill Projects and the potential for future proposals for development of geothermal energy in the area. There is strong public opposition to geothermal energy development in the Medicine Lake area. The distance between the monument and the proposed geothermal energy developments and the local hydrogeologic conditions make it unlikely that the planned amount of groundwater use for either of the previously proposed projects would have directly impacted the water resources of the monument.

The biggest impacts to the monument from geothermal development would probably be from the ancillary development: the roads, power lines, increased industrial traffic, noise, and night sky lighting.

Hydrogeology of the Proposed Geothermal Developments

A general description of the regional groundwater hydrology of the Medicine Lake Highland, as described in the EIS (U.S., 1998) for the two projects includes the following main features.

1. Thick and very permeable geologic material comprised of lava flows, cinders, and pumice that readily allow infiltration of rainfall and snowmelt.
2. A large saturated thickness of fresh groundwater in these permeable geologic materials that ranges from a few hundred feet to 2000 feet.
3. An impermeable, high-temperature gradient zone underlying the freshwater aquifer that forms a thick (1500 to several thousand feet) barrier to groundwater flow between the near-surface, fresh-water aquifers and the geothermal reservoir.
4. Radial flow of groundwater away from the caldera rim of the Medicine Lake Volcano (i.e., from recharge areas in the Medicine Lake Highland toward the monument).

The Fourmile Hill Project planned to extract hot water from deep wells constructed into geothermal reservoir, at depths of 5000 feet, or deeper. The water would be used to generate electricity and then reinjected into the geothermal reservoir. Only a small amount of water from the shallow aquifers would be consumed in support of project operations. It is highly unlikely that the Fourmile Hill Project could have impacted the hydrology of the monument because: the geothermal resources are isolated in a very deep aquifer, the small amount of potable water that would have been used for the project, the large distance from the proposed project to the monument, and the large recharge rate to the groundwater system from rain and snowmelt on the porous volcanic rock on the flank of Medicine Lake Volcano. The proposed project was reviewed by USGS, California regulatory agencies, and private consultants. Their conclusions, as documented in the final EIS, were that there would be no significant impacts to groundwater in the project area. Thus, it is highly unlikely that the project could significantly affect adjacent

watersheds, especially considering the large volume of groundwater stored and flowing through the groundwater system in the area.

Effect of Groundwater Pumping on Water Levels

Prior to 2001, there was very little large-scale groundwater pumping in the area. Farm land was irrigated with surface water. In 2001, the effects of a drought and the need to provide water for endangered fish species caused the Klamath Project Operation to reduce surface water deliveries to 26% of normal (California Department of Water Resources, 2004). In the Tule Lake Subbasin, 35-40 high-capacity wells were constructed to provide irrigation water. Most of the irrigation wells were capable of producing several thousand gallons per minute and some produced more than 10,000 gpm.

Gannett et al. (2007) documented up to 5-10 feet of water table decline in the Panhandle and Copic Bay areas adjacent to the northeast corner of the monument between spring 2001 and spring 2004. Many of the shallow wells in the Tule Lake Groundwater Subbasin had no water level decline during this same period. The California Department of Water Resources continues to monitor water levels at several wells in the Tule Lake Subbasin. An example of the seasonal water level variation and decline for Well 46N-5E-16N, located in the central part of the "Panhandle" (Figure 3), is shown in Figure 12. There has been about 5-6 feet of water table decline in the well from late 2001 to spring 2007. Water levels in wells in the monument show a decline of 1½ to 2 feet per year over the same time period (Figures 5, 7, 9, and 10).

The observed water level decline in Well 46N-5E-16N is less than the observed rate of decline at wells in the monument despite Well 46N-5E-16N being located closer to the center of groundwater pumping. One possible explanation for this disparity is that Well 46N-5E-16N is located in the midst of the irrigated farmland and there is probably a significant amount of recharge to the water table from infiltration of the irrigation water. Wells within the monument do not have the benefit of increased recharge, instead showing only the effects of a general lowering of the water table over a large area.

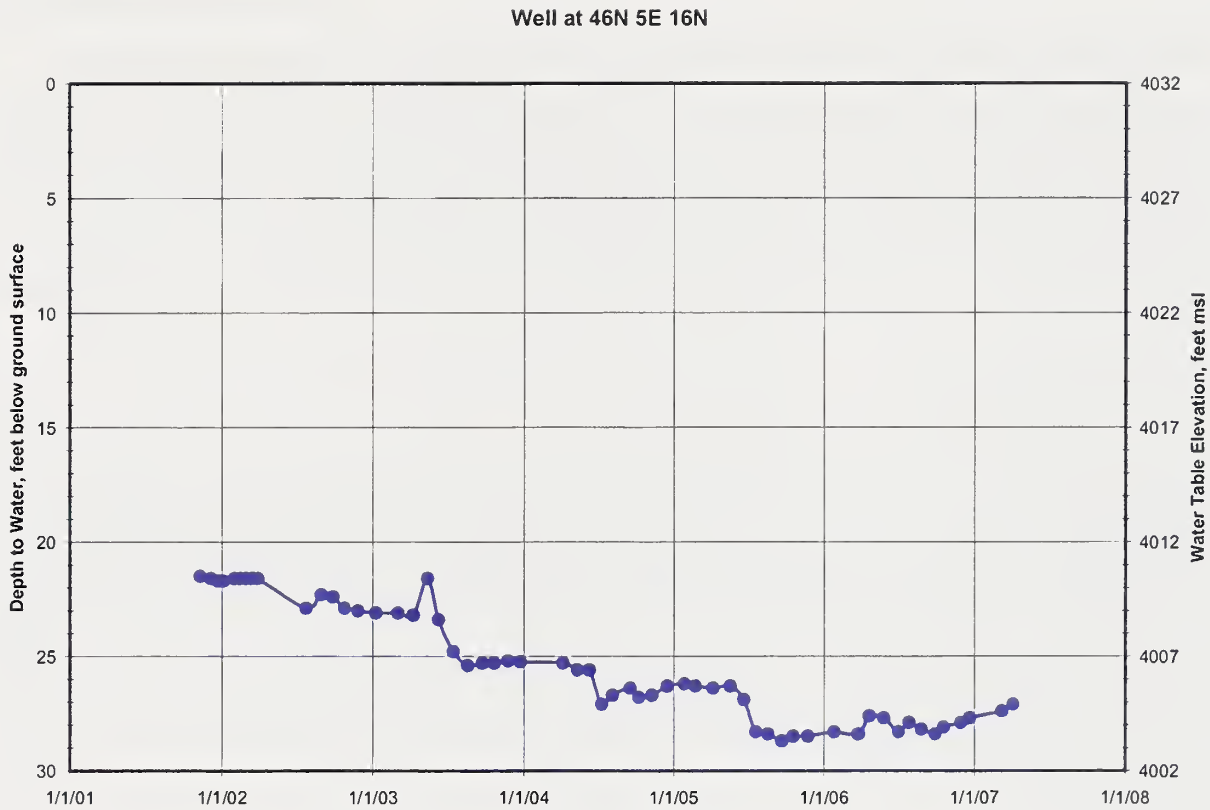

Figure 12. Hydrograph of water levels in Well 46N-5E-16N near the monument.

This is the response we would expect to observe in this type of hydrogeologic environment. Pumping large amounts of groundwater from a very permeable aquifer should cause a small drawdown of the water table over a large area.

Water levels in the three wells at the monument that continue to be monitored (Headquarters, Gillems Camp, and Petroglyph Section) appear to have stabilized since late 2005. No increased drawdown was observed during the 2006 irrigation season, and water levels in the Headquarters and Gillems Camp wells rose slightly toward the end of 2006 and early 2007. It is unknown whether this is a result of less groundwater being pumped, increased recharge from above average precipitation, establishment of new equilibrium conditions for the groundwater system, or some combination of these factors. Continued regular monitoring of water levels at wells in the monument, and throughout the Tule Lake Groundwater Subbasin, will provide data to help evaluate the cause of water level fluctuations and to predict future water level trends.

Recent climatic trends may affect groundwater levels. Figure 13 is a graph of the Palmer Hydrological Drought Index for Division 3 in Oregon and Division 1 in California. Lava Beds National Monument straddles the boundary between the two divisions. The Palmer Hydrological Drought Index (PHDI) quantifies the hydrological impacts of drought on reservoir levels, groundwater levels, etc. These hydrological impacts take longer to develop and it takes longer to recover from them. Positive values indicate wetter than normal periods. Negative values indicate drought periods.

The drought indices show that the late 1990s were a wetter than normal period. A moderate to severe drought affected the area in 2001 and 2002, at the same time that surface water supplies for irrigation were cut back. Drier than normal conditions persisted into the early part of 2005. The area has been wetter than normal since early 2005 and throughout 2006. The recent wetter-than-normal conditions may be partly responsible for the stabilization of groundwater levels at the monument.

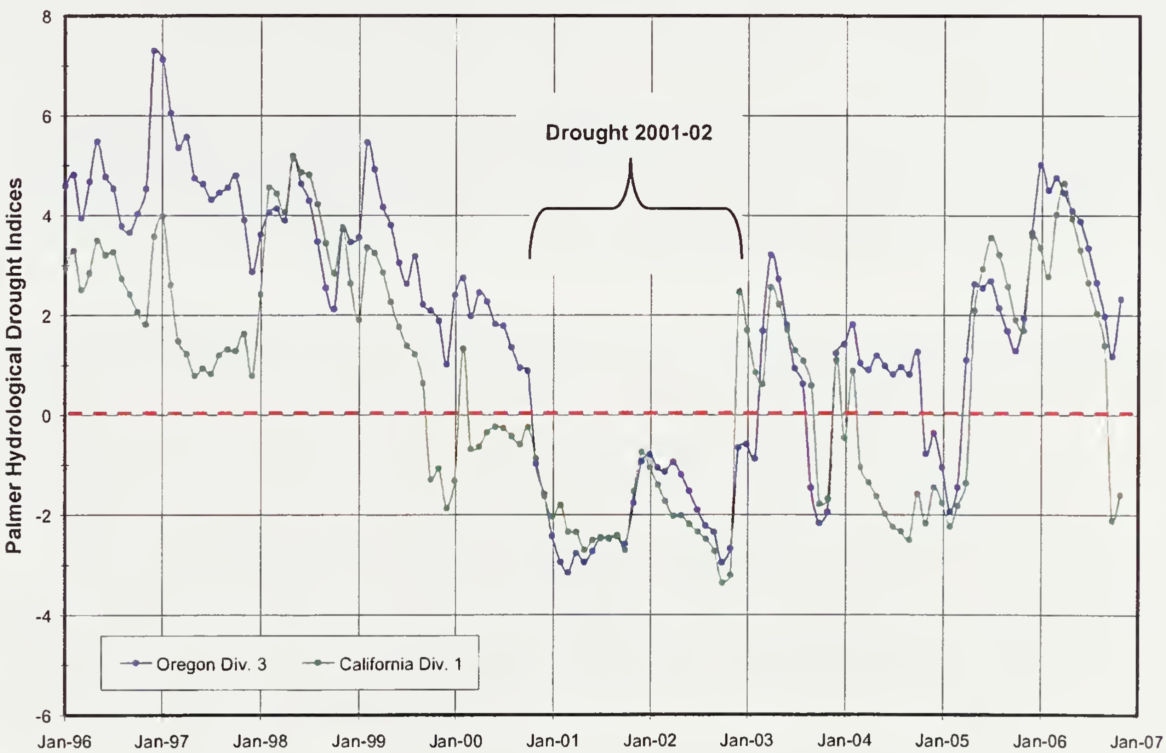

Figure 13. Palmer Hydrological Drought Indices for Lava Beds National Monument.

Recommendations

Park staff should remain alert to the disposition of geothermal energy leases in the Medicine Lake area. Currently, it appears that the proposals for development at the Fourmile Hill and Telephone Flat sites will not proceed. If either of these projects are revived, or other projects are proposed, they should be closely examined to assess their potential to affect Lava Beds National Monument.

Monitoring groundwater levels at wells in the monument should continue indefinitely. If the USGS decides to discontinue the monitoring, then the park should acquire a water level meter and measure water levels quarterly. Several more years of data will be needed to evaluate the long-term effect of the increased groundwater pumping for irrigation on adjacent agricultural lands.

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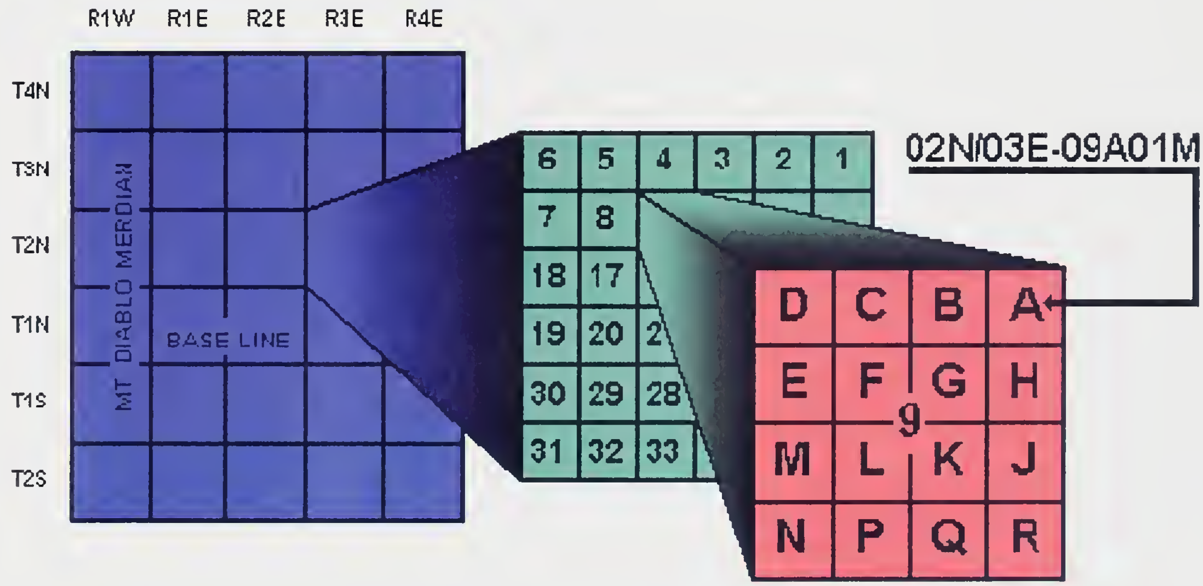
California Well Numbering System

Wells monitored by the Department of Water Resources and cooperating agencies are identified according to the State Well Numbering system. The numbering system is based on the public land grid, and includes the township, range, and section in which the well is located. Each section is further subdivided into sixteen 40-acre tracts, which are assigned a letter designation as shown in the figure below. Within each 40-acre tract, wells are numbered sequentially. The final letter of the State Well Number refers to the base line and meridian of the public land grid in which the well lies. "M" refers to the Mount Diablo base line and meridian; "S" refers to the San Bernardino base line and meridian; "H" refers to the Humboldt base line and meridian.



In this example, the well is located in Township 2 North, Range 3 East, in the NE¼ of the NE¼ of Section 9. Township and Range locations in the vicinity of Lava Beds National Monument are based off of the Mt. Diablo base line and meridian.

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